Performance Analysis of Fuzzy based HESS for Electric Vehicle

Kamal Kishore, Er. Ashwani Kumar[2]
M.Tech Reserarch Scholar, Asstt Professor
Hindu College of Engineering, Sonipat, Haryana

Abstract — This work presents performance analysis of Hybrid energy storage system (HESS) with battery management system. This system includes the fuzzy-PSO based controlling scheme for battery state controlling and provides optimized output for electric vehicle. The initial phase provides a study on hybrid energy system with its controlling by MPTT controller. The next phase is controlled by fuzzy based controller for improving its performance. The use of fuzzy controller provides better stability in system as compared to other conventional controllers. All simulations are implemented using MATLAB/Simulink Tool.

Keywords—Hybrid Electric Vehicle, Battery Management System, PSO, Optimization etc.

I. INTRODUCTION

The ceaselessly draining the condition of the soundness of the climate has pushed analysts to lead a far-reaching assessment of fuel-cycle emanations and energy use at the worldwide level. Studies show that the expansion of the CO_2 discharge accounted by transportation is about 22% from 14 billion tons to 31 billion tons in the course of recent years. Universally, private vehicle takes up half of the oil utilization and adds to 77% of carbon monoxide and 49% of nitrogen oxide outflows [3]. The pace of ozone harming substance emanation, alongside the developing interest for petroleum derivatives on the planet has advanced the requirement for elective transportation fills and progressed vehicle advances. The change from conventional inward ignition (IC) motors to Electrified Vehicles (EVs) makes a significant effect on oil reliance and results in maintainable transportation with improved ecological conditions.

Planning an improved energy, the board methodology is of fundamental significance and goes connected at the hip with the general advancement of the vehicle regardless of whether there are profoundly productive segments in the drive-train, using them in a wasteful way will break down the whole even handed of vehicle advancement. The fuel sources and their administration in an electric vehicle keep on being a significant test for automakers to expand the all-electric driving reach. Fuel sources in monetarily accessible electric vehicles are for the most part a battery module, a ultra capacitor (UC) module, or a blend of both Generally, batteries have higher explicit energy than ultra-capacitors, and consequently, can give additional capacity to longer timeframes.

The remainder of paper is requested as follows. In segment II, it provides the concept of optimal sizing of electric hybrid sources. In Section III, It characterizes the general battery management system. Proposed model is presented in Section IV. Results are presented in Section V. At last, conclusion is clarified in Section VI.

II. RECENT TRENDS RELATED TO ENERGY MANAGEMENT SYSTEM

Batteries as energy source require frequent replacement which is both costly and inconvenient. To make each node energy autonomous energy harvesting from ambient environment is used to power the sensor node, but due to intermittent nature of solar energy, the storage buffer is essential for reliability. Two schemes are available for energy storage, batteries and electrochemical double layer capacitors (supercapacitors). Each have their own advantages and limitations, batteries have high energy density and low leakage current than supercapacitors. However, supercapacitors offer the advantage in terms of the lifetime and high-power density. But the properties like low specific energy and high leakage charge makes them unsuitable to be used as primary storage in energy harvesting circuits as it would make the system more bulky and inefficient. Supercapacitors can complement battery and act as secondary storage as they have high power density and long lifetime in terms of large no of charge/discharge cycles the features in which battery lags. Battery-Supercapacitor hybrid storage scheme offers an advantage in terms of increase lifetime but suffers from low efficiency due to high auto consumption of supercapacitor converter. For achieving high energy efficiency, we need to cater these issues.

T.Rout et al. [2018] [18] presented that Energy stockpiling is a crucial part for a PV framework. The correlation of Photovoltaic energy stockpiling framework between mix of battery-supercapacitor (HESS) and just battery is portrayed in this paper. In this paper, there is an investigation of independent Photo Voltaic frameworks with Passive kind BSHESS and semi dynamic BSHESS are introduced. For better arrangement, the diminished battery stress and broadened battery life expectancy Rule Based Controller (RBC) and Filtration Based Controller (FBC) are utilized. From reproduction result it is inferred that if there should arise an occurrence of semi dynamic BS HESS, battery life expectancy increments with diminishing battery top current and improving the normal State of Charge (SOC) contrasting and alone battery stockpiling.

A. Rezaei et al. [2018] [19] presented that the energy the executives (EM) of module crossover electric vehicles (HEVs) is normally separated into two modes: charge-consumption mode and charge-supporting mode. This paper presents the ideal adaption law for a versatile energy utilization minimization methodology (ECMS) in control exhaustion mode for module HEVs. To introduce the ideal law, a specific versatile ECMS is chosen, known as CESO. CESO has recently been presented for arrangement and equal HEVs in control supporting mode. Here, by presenting the ideal adaption law in control exhaustion mode, CESO technique is extended to charge-consumption mode for module HEVs.

L. Chandra et al. [2018] [20] displayed the best-in-class time of electrical force frameworks, occupants get an opportunity to deal with their energy consumption. This paper presents Smart Homes Energy Management System (SHEMS) to help the network and ideal activity of a savvy home as far as limiting the absolute energy cost. Such sorts of home include rooftop top PV, electric vehicle (EV), shrewd apparatuses and energy stockpiling framework (ESS). The EV battery can be charged during low interest period and put away force can be taken care of to home just as framework during top burden hours. The energy trades are esteemed taking into account net metering principles considering a unique estimating plan. At long last, contextual investigations are doing to approve the outcome.

O. S. Vasilkov et al. [2019] [21] presented similar examination of different sorts of energy stockpiling gadgets. Highlights of joint batteries and supercapacitors application as a cross breed electric force stockpiling are thought of. A numerical model of a mixture energy stockpiling gadget was worked to assess the proficiency of sharing and deciding the utilizations of such stockpiling gadgets.

V. M. Nayanar et al. [2019] [22] presented that electric vehicles have acquired fascination all through the world because of its favorable position of green innovation and diminished discharge. . In addition, they are being controlled by battery would be the most ideal alternative of supplanting current petroleum or gas subordinate vehicles. There are a few downsides related with battery; it has restricted lifetime and cost is high. Consequently, it is hybridized with other energy stockpiling frameworks, for example, Ultra capacitor/Supercapacitor. This work utilizes a fluffy and Pi control for Energy the board framework for Electric Vehicle and Simulation climate picked is Matlab/Simulink.

K. KOUKA et al. [2019] [23] presented that the reception of the photovoltaic electric vehicle charging stations has been on the ascent. In this paper, a framework associated electric vehicle charging station controlled a by photovoltaic nearby planetary group and a bunch of batteries as capacity framework, is assessed and investigated. The main boundary for overseeing the framework is the immediate current transport voltage. The framework or the energy stockpiling framework can supply the electric vehicle charging station to keep up the transport voltage at its level. This oversight is tried by reproducing the charging framework under various irradiance conditions considering the expense of the energy transmission and the condition of charge of the battery. The outcomes approve the presentation of the proposed energy the executives and the appropriate activity of electric vehicle charging station.

R. Katuri et al. [2019] [24] proposed another control approach for a smooth progress among Battery and Ultra capacitor (UC) of Hybrid Energy Storage System (HESS) for Electric Vehicle (EV) application. The UC is utilized for top force necessity and ordinary force prerequisite can be send by the battery and goes about as a base source. Math Function Based (MFB) regulator is planned by taking four individual number related capacities comparing to the speed the engine. The planned MFB regulator joined with neural organization regulator strategies another mixture regulator with that ready to produce the control heartbeats to the converter, which might be unidirectional converter (UDC) or Bidirectional converter (BDC). At long last, whole circuit has been planned with two half and half regulators and recreated in MATLAB/Simulink and execution investigation additionally made dependent on various variables, all deliberate qualities are introduced.

Z. Guan et al. [2019] [25] presented that Research on the crossover power supply with the blend of battery and ultra-capacitor is a hotspot in the field of electric vehicle research. Battery has high energy thickness, ultra-capacitor with high force thickness. To sensibly control the yield intensity of the two, in order to accomplish more productive activity of electric vehicles, we did an itemized investigation of the activity method of the half and half force supply framework, and proposed an energy the executives procedure dependent on speed and rationale edge control. In the MATLAB/SIMULINK reproduction climate, the half and half force supply of electric vehicles and the proposed control methodology are reenacted. The reenactment results show that: the ultra-capacitor current can precisely follow the reference current, and the proposed control procedure can sensibly appropriate the yield of the battery and the ultra-capacitor to meet the energy yield under various force necessities.

P .Aruna et al. [2019] [26] centered around advancement of Energy Management System (EMS) in Electric Vehicles (EVs) and its segments in different ages. While portraying the EMS in detail, it is required to depict the noteworthiness of the battery in an EV. The battery assumes a significant part in electric vehicles to convey the necessary capacity to the electric engine for the travel. For protected and solid activity of batteries on electric vehicles, the web based observing and states assessment of the batteries is fundamental. This can be accomplished by a Battery Management System (BMS). Next to BMS, there should be a command over the ideal force stream between battery, converters and different pieces of a vehicle. This control is called Energy Management System (EMS). Subsequently, by and large vehicle execution firmly relies upon this EMS. Accordingly, the plan of EMS picks up significance to diminish the energy utilization or improvement in framework proficiency, to build the battery life period and to accomplish spotless and proficient vehicle framework by guaranteeing long item life and safe drive insight.

I. Goswami et al. [2020] [27] advanced a methodology for energy the board in an electric half and half vehicle (EHV) with different force sources, involving power module (FC) as the essential wellspring of energy while battery and supercapacitor (SC) as the auxiliary wellsprings of energy. The electric vehicle draws its necessary energy from power device, while the auxiliary wellsprings of energy act the hero in making up for the lacking force during speeding up or in engrossing the abundance power during slowing down activity. The synergetic utilization of the optional sources demonstrates its adequacy in improving vehicle effectiveness, decreasing the utilization of hydrogen apparently, and getting power and unwavering quality in the activity of the framework all in all. The proposed methodology facilitates the force divide between the different fuel sources in a manner to ideally satisfy the force necessity of the vehicle.

III. HYBRID ENERGY STORAGE SYSTEM FOR EVS

During the last few decades, the negative environmental impacts of petroleum based vehicles have ignited the interest toward Electric Vehicles (EV) with low or zero emissions. An Electric Vehicle uses one or more electric motors for propulsion. One major challenge in the mass adoption of EVs and HEVs is their Energy Storage

System (ESS). Classical electrochemical batteries have several limitations:

- Lower energy-density compared to petrol-based fuel, which affects the weight and the range of the vehicles. The specific-energy of petrol and Lithium-Ion (Li-Ion) batteries (the dominant battery chemistry in modern EVs) are 13 kWh/kg and 0.2 kWh/kg, respectively. Considering a typical energy efficiency of 20 % for the ICEs and 90% for the electrical drives, the effective specific-energy of petrol is 14 times higher than that of Lithium-Ion batteries, resulting in a very limited range for EVs.
- The charge time is another prohibitive factor and charging time varies with the charging levels [5]. For instance, using an on-board 3.3 kW charger, it takes 7 hours to fully charge the Nissan Leaf's 24 kWh battery pack.
- The battery lifetime is another major concern and is usually not sufficient for traction applications. Numerous battery chemistries are available and the best choice of battery is application dependant.

Implementing low-cost, high-density and power-efficient energy storage system is one of the key technological hurdles for enabling future mass-adoption of EVs. Different storage technologies, such as fuel cell (FC), flywheel and ultra capacitor (u-cap), can be combined with the batteries to form a HESS for an EV. Fuel cell generates electricity from the reaction of the fuel and oxidant in an electrolyte. FC has several advantages including high conversion efficiency, zero or very low emission, quiet operation, fuel flexibility, durability and reliability. The main drawbacks of FCs are high cost and longer response time compared to batteries and u-caps.

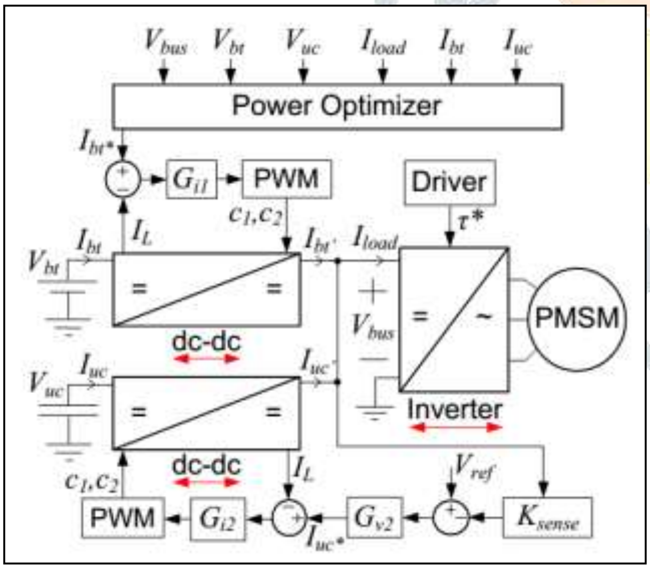

Fig 1: Structure Model of HESS

With two energy sources inside the vehicle, it is possible to control the power-mix between the two sources depending on the HESS configuration and source interfaces. Implementing low-cost, high-energy and high power-density storage that performs reliably for 10-15 years is crucial for the mass adoption of EVs. To summarize, the main objectives of an automotive HESS are to (1) minimize the battery stress during rapid accelerations in order to limit long-term capacity fading and maximize the capture of the Regen, while reducing the wear on the mechanical brakes. Accurately predicting the battery lifetime extension due to the reduction in dynamic currents under real drive-cycle conditions is a major challenge, and is currently under investigation.

1. Role of Different Converters

The converters are used to control the power flow through the circuit. Although a wide variety of converter topologies are available, only a dozen basic ones are used in practical power design. The different converter topologies used in the proposed circuit are explained below:

A. DC-DC Buck Converter

A Buck converter steps down the DC voltage and is required wherever source voltage is higher than the load voltage. This converter interfaces the PV panel with internal DC bus and is used to realize the MPPT of the panel. The controller adjusts the duty cycle of the switch to control the input voltage VPV for maximum power point. For effectively controlling the input voltage, equation (1) suggest that VBUS is kept constant.

$$\frac{Vbus}{Vpv} = \frac{D}{1-D} \qquad (1)$$

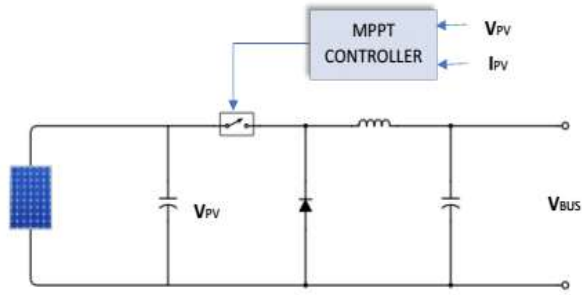

Fig 2: DC-DC Buck Converter connected to the First Stage

B. DC Bidirectional Buck Boost Converter

This converter allows bi-directional flow of power with different topologies. The converter operates in step-down mode during the charging process and in step-up mode while discharging. This choice is dictated by the voltage level of the battery with respect to the DC bus. The converter has a current controlled loop, reference for which is determined by the power manager.

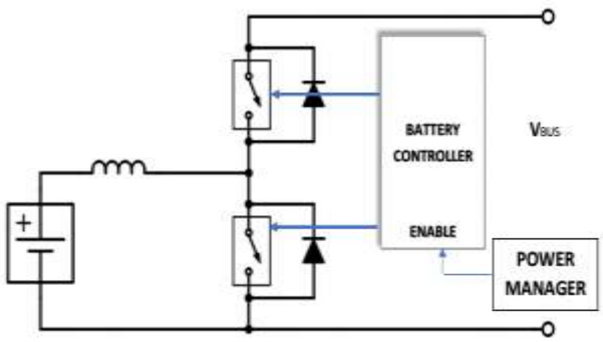

Fig 3: DC-DC Bi-directional Buck-Boost Converter connected to Battery

C. DC-DC Supercapacitor Converter

The dc-dc supercapacitor converter is a bidirectional converter, as shown in fig. 4. This converter is responsible for controlling DC bus voltage in a narrow band by acting as a source or sink depending on the instantaneous power budget. The proposed architecture is based on the direct transfer of solar power to load bus. Due to intermittent nature of solar energy, the energy mismatch between source and load is normal, which manifests as undesired conditions of under and over voltage on DC bus. Supercapacitor acts as a shock absorber to the system and smoothens out these energy fluctuations.

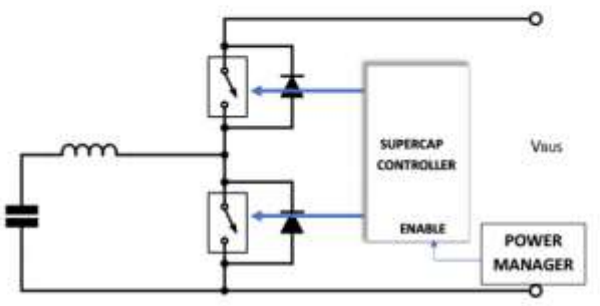

Fig 4: DC-DC Bi-directional Buck-Boost Converter connected to Supercapacitor

2. Introduction to Fuzzy Logic

Fuzzy logic controllers are found in a vast number of products such as washing machines, rice boiler, air condition and camera autofocus. The success of fuzzy logic controllers (FLC) is due to their ability to deal with the knowledge that is represented in a linguistic form instead of the conventional mathematical method. FLC is designed based on the experience of the expert or the system user rather than modelling the system mathematically and then try to solve complex equations as control engineers used to do conventionally. This concept gives the strength and motivation to formulate fuzzy logic as Lofti Zadeh developed and established the fuzzy set theory in 1965. The main advantage of fuzzy logic is its ability to implement experience and knowledge of a system that is sometimes can be difficult to derive its mathematical model accurately and completely or ill-defined one or input data is not precise [98]. Fuzzy logic is a rule-based system that is designed by linguistic fuzzy rules, that relate the output command to the input data. Fuzzy rules are in the form of if-then rules where an expert should them so they will cover all possible conditions the system is expected to go through.

Any fuzzy system has four components to work as fuzzification rule-based inference, rules, and defuzzification. Fuzzy logic can receive imprecise inputs that will be converted into fuzzy values as a degree of membership of linguistic fuzzy sets then the rule-based system will infer the proper result. the output linguistic value based on the rules and the inference type will be the fuzzy output result that requires a defuzzification process which converts these linguistic values to real values.

3. PSO Optimization

Population-based algorithms are well suited for solving mixed integer nonlinear optimization problems. Among the population-based algorithms, PSO and GA have been investigated for various applications for the optimization of energy systems. PSO, which is a population-based algorithm, invokes the natural behavior of particles. Introduced by Kennedy and Eberhart, it was initially inspired by the social behavior of flocking populations. This method can efficiently solve multidimensional non-linear functions. The PSO algorithm starts with random initial populations within the search space, which are updated at each iteration. The updating process is influenced by the personal experience of each particle (personal experience) as well as its neighbours' experiences (global experience). Updates based on personal and global experiences are called exploitation and exploration, respectively. Each population is an n-dimensional vector that includes all the decision-making variables (n is the number of the decision variables). In an n-dimensional search space (n is the number of the decision variables), the position of each agent or particle represents a possible solution. For example, in this study, the size of the components and the cooling ratios are included in each population. Each agent is defined as a position and will be updated at each iteration that directs the agent towards the optimal solution. The initial position of each agent is completely random and the initial velocity is usually assumed zero.

IV. PROPOSED WORK OF SYSTEM

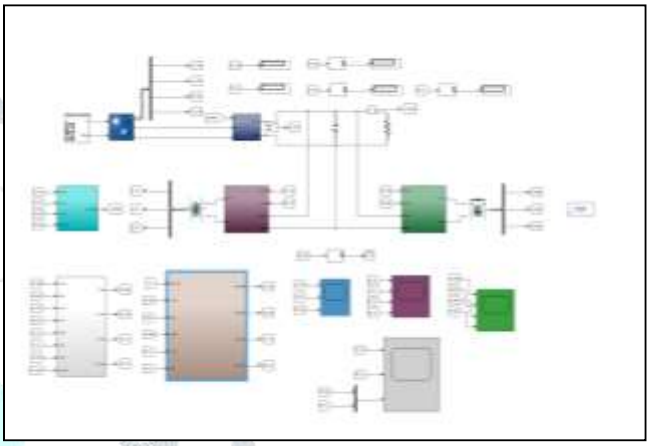

Fig. 5: Proposed Simulink Model of HESS

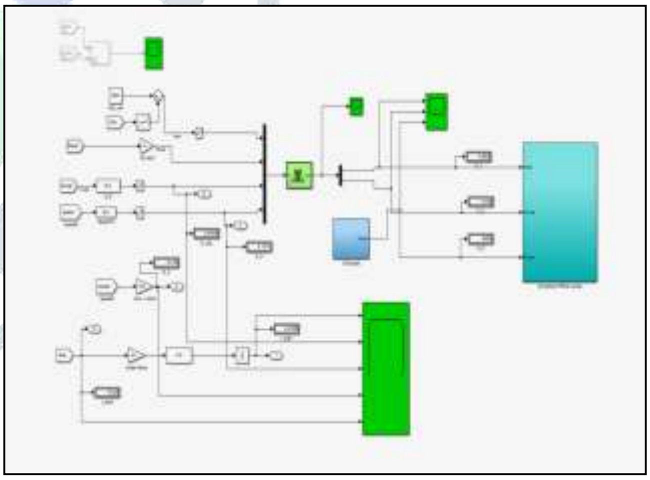

Fig. 6: Proposed Simulink Model of HESS with Fuzzy-PSO

The proposed system model is shown in Fig 5 & 6 respectively. Figure shows the conventional schematic of a hybrid energy storage system. By using a bi-directional DC/DC converter to link the ultra capacitor and the battery, the UC voltage can be varied over a wide range. Moreover, the UC banks nominal voltage can be lower than the DC link. Since the battery is connected to the DC link directly, the voltage of the DC link can be maintained relatively constant. However, this configuration has certain disadvantages. As the UC can only partially absorb the regenerative braking energy, smooth control is not obtained. Moreover, a large size bidirectional converter is required in order to effectively handle the power of UC.

The PV module is used for solar energy harvesting which is the main source of energy for the sensor node. The output power from PV is not stable and depends on the irradiance and temperature. The output power from PV array is different at different irradiance and temperature level. At the particular irradiance and temperature level, the PV curve of the photovoltaic panel is non-linear and a maximum power point exists. Therefore, for maximum utilization of solar energy, we require a maximum power point tracker (MPPT). This hybrid storage technique offers increased lifetime. Due to low leakage charge battery is used for holding the charge for a long time and is discharged only when solar energy is not available and supercapacitor storage is exhausted.

A solar cell is a solid electric device which consists of a p-n junction fabricated from a semiconductor material of moderate band-gap (usually silicon). It behaves as a normal p-n junction diode in dark and has non-linear V-I characteristics. However, in the presence of light, it absorbs photons having energy greater than the band gap energy. This results in the creation of electron-hole pairs. These charge carriers are separated by internal electric field and result in a current proportional to incident photons.

The system is very dynamic, nonlinear, unpredictable, has a lot of uncertainty and its mathematical model is somehow complicated so the best choice is to use one of the expert-based systems, intelligent, such as fuzzy logic. The fuzzy logic will manage the flow of energy throughout the system to assure high-quality uninterruptible power delivery to the demand regardless of intermittent in the power generation. The controller has three main states as discharging mode which allows battery and fuel cell to support the load, balance mode when supply power equals demand and controller at rest, and lastly, charging mode that allows battery and water electrolysis receive an excess of energy and store it to be used later.

The function of a control mechanism is to maintain certain goals from the system at different desired values. The ideal control system is a linear system which relates its inputs directly to the outputs. Nevertheless, in practice, instabilities affect the system output being controlled and cause deviation from the proposed set points. The closed-loop system uses the signal feedback to correct the controller output to meet the desired value. Controlling a system complex as HESS is difficult to achieve using conditional methods. Therefore, FLC is a more suitable solution since it covers a high range of possible working situations with an acceptable level of uncertainty or lack of future information.

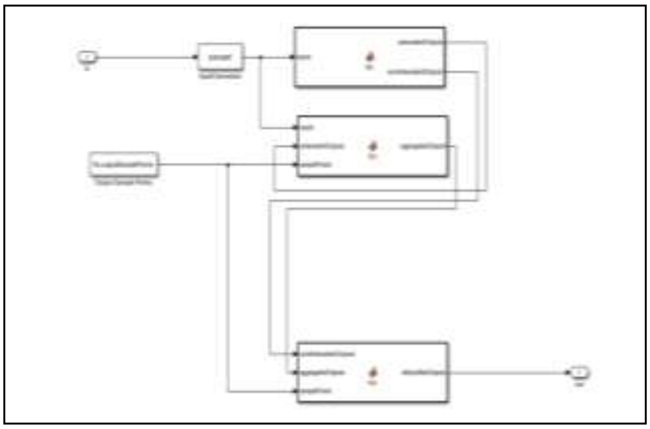

Fig 7: Fuzzy Logic Modelling with HESS

V. RESULTS & DISCUSSION

The entire system modelling is done in Matlab/Simulink. This system consist of battery with a bidirectional converter and UC with a bidirectional converter. The fuzzy logic controller setup is used with PSO optimization to restore the entire energy during regenerative breaking. During regenerative breaking operation, the UC is charged. And Uc Soc will get increased during regenerative mode of operation. All results are shown with & without fuzzy-PSO to provide effectiveness of system.

The purpose of supercapacitor in the circuit is to smoothen out the energy fluctuations, a condition which is normal when primary energy source (PV Panel) is intermittent in nature. The results shows the effectiveness of the supercapacitor in case of excess power conditions.

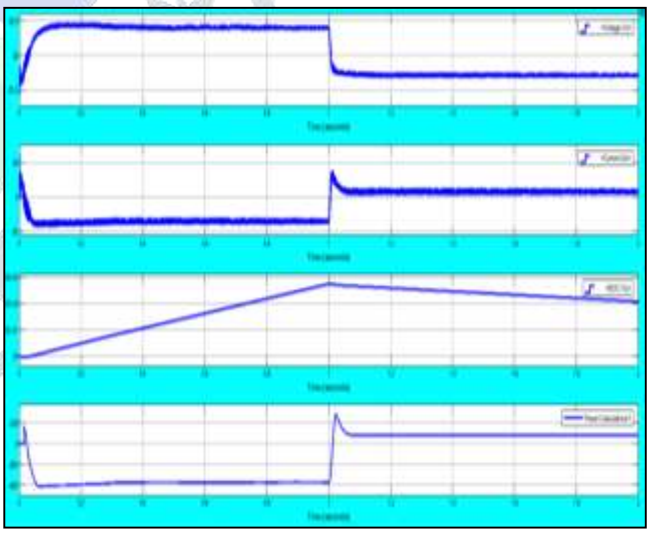

Fig 8: Performance Parameters of Battery System

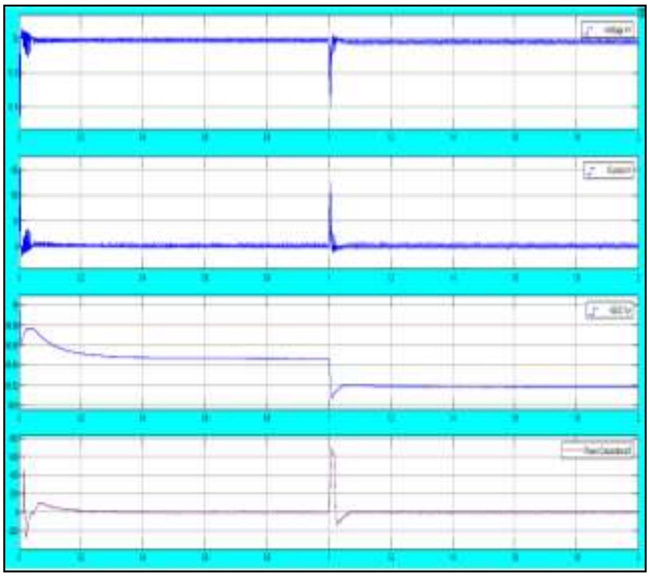

Fig 9: Performance Parameters of Supercapacitors

Fig 10: Performance Parameters of HESS with PV Array

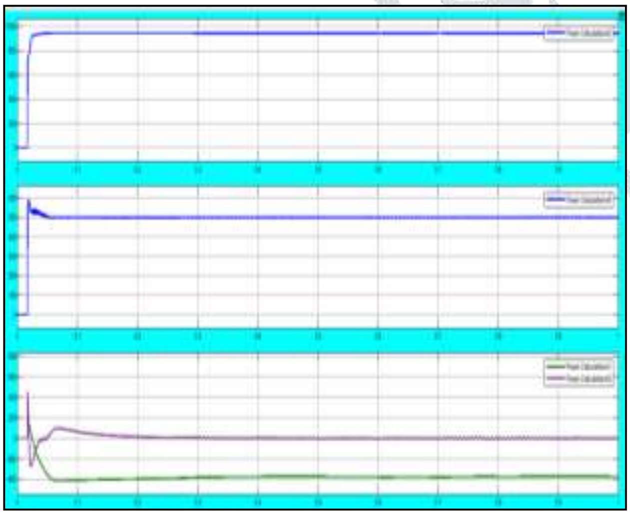

Fig 11: Power Analysis of HESS with Battery/SC

This section provides the HESS results with Fuzzy-PSO system. Fuzzy uses a rule based system with membership function for providing smooth output in terms of power maximization. A membership function is a curve that defines how each point on the input space (or universe of discourse) is mapped to a membership value (or degree of membership) from 0 to 1. Triangular membership functions were used for all the input and output variables in this work. Hit and trial technique was used to develop the membership functions on MATLAB. The use of PSO provides smoothness of results with their optimization.

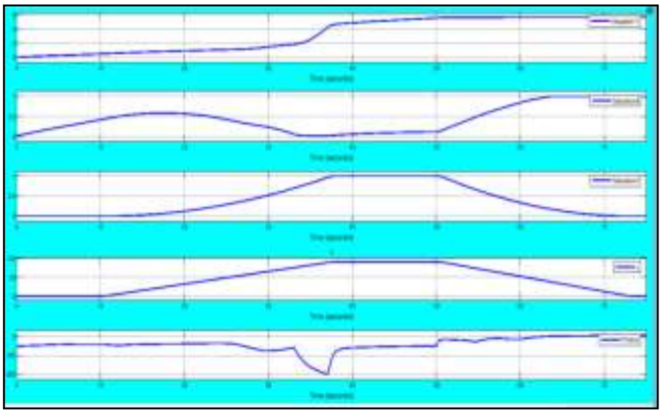

Fig 12: Charge & Discharge Output by Fuzzy Controller

VI. CONCLUSIONS

This work provides the hybrid energy system designing with PV array. It also presents the HESS controlling with fuzzy based controller with PSO optimization. The simulation results show that the battery discharge current is reduced to very low levels by software control and supercapacitor is dripped charged from it just before the arrival of peak power, this ensure that the discharge rate of the battery is low which will result in increased lifetime of the battery. By using the supercapacitor for supplying only peak power will reduce the auto consumption of converter and will improve the efficiency of the overall circuit. The results of the design showed that the use of fuzzy logic in monitoring supply power and charging and discharging of battery for the purpose of proper power flow management delivered desirable results as seen in the scenarios. This work showed that the use of fuzzy logic control in energy flow management in hybrid energy systems gives the advantage of ease of control design since there is no need to develop complex mathematical models as required in conventional control techniques.

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